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APPLICATION FOR UNITED STATES PATENT

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Invention: MISSILES AND CONTROL SYSTEMS THEREFOR RECEIVED

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SPECIFICATION

DECLASSIFIED ~~SECRET~~ ORIGINATING AGENCY

TITLE: MISSILES AND CONTROL SYSTEMS THEREFOR.

This invention relates to homing missiles and control systems therefor.

A homing missile will generally comprise a target tracker mounted in the missile tip, which tip is formed as a window giving the tracker a field-of-view extending forwardly from the missile tip and, evenly and symmetrically, all around the missile roll axis. Normally the tracker is spatially stabilised, for example by gyroscopic means, so that it maintains its view of the target despite manoeuvring of the missile, and that spatially stabilised position is controlled, for example by gyro precessing means, so that it maintains its view of the target despite relative movement of missile and target which produces a change in the direction of the line-of-sight between missile and target. Meanwhile, in response to signals indicative of the relative position of the target tracker and the missile, a control system guides the missile according to some chosen navigation law to intercept the target.

It may be advantageous to move the target tracker and its window back away from the missile tip, the shape and material of the tip can then be optimised, say for the high degree of kinetic heating

at this point, without having to consider transparency

and lack of distortion for the tracker-sensitive

radiation, while the window may become *less* subject to and/

or more easily protectable against such kinetic heating.

Then, however, it may be difficult or impossible to

provide the tracker with an all *around* field-of-view.

In fact, it is not inherently essential that the tracker

should have an all *around* field-of-view since,

theoretically at least, it is possible, say by

manoeuvring the missile and target tracker, to move

the restricted field-of-view.   For example, if the

field-of-view is of rectangular cross-section and

extends between the roll axis and one side only of the

missile, then the missile and tracker can be rolled

around to maintain the target within the restricted

field.   Now, however, due mainly to limitations in

the capabilities of available target trackers, the

space stabilising means for the tracker, and control

systems, particularly the autopilot guidance system

which generally forms part of such a control system,

problems of instability may arise and/or it may

simply not be possible to move the tracker fast

enough to keep the target in view.

An object of the present invention is to provide

a control system for a missile of which the target

tracker has a restricted field-of-view, the system

nevertheless permitting adequate performance for

navigating the missile to target interception.   A

preferred further object is to provide a control

system which in some circumstances, is able to tolerate

some loss of sight of the target by the target tracker.

According to the present invention, there is

provided a homing missile comprising a target tracker

and drive motor means for producing relative movement

of members comprised in the missile including control

members for steering the missile in a lateral direction,

the missile being such that said target tracker has

a field-of-view which is restricted at any instant to

less than an all-around field-of-view and, to compensate

for said restriction, said drive motor means is

operable for rotating the said restricted field-of-view

with respect to the missile roll axis, for example by

controlling roll of the missile itself, the missile

further comprising a control system connected between

said target tracker and said drive motor means and

including look-angle demand signal deriving means for

deriving signals indicative of desired positions of a

target relative to the missile, said signals including

lateral steering signals and also including angle

signals indicative of the angular arguments of the

polar coordinates of said desired position, first

limiting means connected to said signal deriving means

to receive said angle signals and for limiting these signals to between two limit values, signal processing means for receiving said limited angle signals and for forming therefrom signals for controlling the rotation of said field-of-view by said drive motor means, second limiting means for receiving said lateral steering signals and limiting them to less than a limit value, and combining means connected to said first and second limiting means and said drive motor means and operable for combining the limited angle signals and the limited lateral steering signals to form steering control signals for controlling lateral steering of the missile.

For a better understanding of the invention, reference will now be made, by way of example, to the accompanying drawings in which:-

figure 1 is a diagram illustrating the restricted field-of-view of the target tracker of a homing missile,

figures 2 and 3 are simplified circuit diagrams of respective parts of the control system of the missile.

The control system to be described is for use in a missile (not shown) having a gyro stabilised target tracker (not shown) with a narrow rectangular or slit-shaped field-of-view F as shown in figure 1. The field F includes but is assymmetrically disposed with respect

to the missile roll axis X. Axes Y and Z are Cartesian axes by reference to which there can be defined respective coordinates LH and LJ indicative of an actual position of a target relative to the missile and coordinates LHn and LJn indicative of a demanded or desired position of the target relative to the missile, i.e. these latter coordinates are those at which the missile control system wants the target to be having regard to the chosen navigation law for the missile flight. In effect, LJ and LH and LJn and LHn define actual and demanded look angles between roll axis X and the sight line to the target. The demands LJn and LHn may be derived by a part of the control system constructed according to known techniques and in accordance with any chosen navigation law which may be a standard known law. By way of example, the law may provide 'Acceleration Vectored Navigation' as described in Guided Weapon Control Systems by P. Garnell and D.J. East (Pergamon Press 1977) Section 9.9. This reference also provides information about examples of the construction and design of parts of the missile and its control system, such as the tracker and the control system part which derives LJn and LHn, which may be standard and are not shown herein. For the example being described, it is assumed that the responses by the missile to the navigation demands for desired

lateral look-angle values (LJn and LHn) are approx-
imately linear in axes not spinning about the missile
but corresponding to it.

The part of the control system shown in figure 2
receives the demands LJn and LHn and modifies them in accord-
ance with constraints imposed by the limited field-of-
view F. In order to move the field-of-view F to
maintain its view of the target, it is assumed that
the missile and the target tracker are to be rolled
about axis X. This invention is still of course
relevant if such rolling does not take place. Other
compensating manoeuvres of the missile can achieve
rotational movement of the field or some mechanism
for relatively moving different parts of the missile
can be used to achieve movement of the field in
addition or alternatively to manoeuvring the missile.

Within the control system part of figure 2,
the Cartesian components LJn and LHn are fed to a
converter device 1 which may be of known construction
and which converts the components to polar coordinates
λ, ϕ where:-

$$\phi = \begin{cases} (\text{arg } (LJn, LHn) & -\pi < \phi \leq \pi \\ 0 & \text{otherwise} \end{cases}$$

and amplitude

$$\lambda = \sqrt{(LJn^2 + LHn^2)}$$

Block 2 computes the absolute value of Ø and block 3 is a threshold detector of which the output signal controls a logic changeover switch 4. If the threshold value of detector 3 is not exceeded, switch 4 passes the current value of Ø from the converter 1 to a limiter 6. This current value is also fed _via_ a delay unit 5 to the second input of switch 4, which input thereby has available a value of Ø previous to the current value. If, due to noise or sudden perturbations, the threshold value of detector 3 is exceeded, switch 4 passes this previous value of Ø onto the limiter 6 rather than the current value thereby reducing the tendency towards violent missile manoeuvres that might otherwise result. The function of the limiter 6 is to provide a value Ø which is equal to the received value of Ø if that value lies between positive and negative limits or which, if the magnitude of Ø equals or exceeds that of each limit, is of the same sign as the received value of Ø but has a magnitude equal to the limit value. The magnitude of each limit imposed by limiter 6 is controlled by a logic changeover switch 7. It is either the polar coordinate magnitude λ multiplied, at gain element 9, by a gain factor K or it comprises a value $\emptyset_{max}$ derived as described later. The control of switch 7 and hence the choice of which of the two mentioned limit values

is imposed by limiter 6 is also described later.

The output value Ød from the limiter 6 is multiplied

by a gain K_p 8 to give the demand Pd to a roll rate

control system. Filtering of Pd using standard

techniques may be required.

The magnitude output λ from converter 1 is also

fed as an input to threshold detector 10 from which a

0 or 1 logic output goes to the OR gate 12. The other

input to gate 12 is derived from a threshold detector 11.

The input to detector 11 comprises a signal indicative

of the target sight line separation from the missile axis.

This signal is calculated by a modulus forming device

from the actual target position signals LH and LJ

supplied by the target tracker. For example the signal

could be calculated as $\sqrt{LH^2 + LJ^2}$. The output Bd

from gate 12 is used to operate the aforementioned logic

switch 7 and also two further logic switches 14 and 15.

The ~~as well as to the converter 1, the~~ look angle demand

signal LJn is fed via a series arrangement of two

limiters 16 and 17 to both a combining device 18 and to

an output line 30 of the illustrated part of the control

system. The limiter 16 sets one of two lower limits, LIJ and

LoJ for LJn, the particular limit chosen being set by

switch 15. Meanwhile, a fixed upper limit for LJn is

provided by limiter 17. The output Ljd from 17 is the

demand in one axis. A computation by device 18 using
the outputs $\emptyset d$ from 6 and LJd from 17 gives $L'Hd$
where

$$L'Hd = LJd \tan \emptyset d$$

The error between $L'Hd$ and LHn is the input to
a limiter 19 controlled by switch 14. The output of limiter
19 is added to $L'Hd$ and is the demand for the other axis
LHd.

The output from converter 1 gives a measure of
the angle between the raw demanded look angle direction
and the current direction of the field-of-view slit.
This is used after some modification to provide an error
signal to drive the missile roll demands. Using the
raw look angle demands instead of the measured look angle
to drive the rolling motion of the missile has the
advantage of providing the missile with advanced warning
of the intended rolling motion so the missile tends to
roll in the right direction long before the measured
look angle makes this necessary. In the presence of
noise and roll limiting by limiter 6 the demands Pd can change sign
rapidly causing time to be lost before the missile is
demanded to roll in the correct direction for instance
if the demands are near $\pm \pi$ rad. The function
performed by blocks 2, 3, 4, and 5 in the drawing tend
to reduce this by keeping the demand nearly fixed when

the demands are near $\pm \pi$ radians and the limiter 6 is

included so that the missile does not roll fast

enough to cause an out of plane or underdamped response

from a standard autopilot that is responding to Lhd

and LJd.

The arrangement of 1, 10, 11, 13 and 12 is used

to indicate when the demands and look angle are small

enough to make the missile fly momentarily with the

target within the axis proximate portion A of the field-

of-view, shown in figure 1. The output from 12 Bd is

false (zero) in this case.

When Bd equals zero i.e. when the target is close

to axis X, the rolling of the missile has little

consistent effect on the pitching of the missile while

the limited H direction look angle capability of the

target tracker is sufficient to retain the target. Thus,

it is appropriate then to limit the roll control demands

to a magnitude equal to $K\lambda$ instead of the normal fixed

limit $\emptyset$max. A similar effect could be achieved by

changing the value of the gain Kp given by gain element

8 instead of the limit given by limiter 6. 18 is used

to give a demand for LH that matches the roll demand $\emptyset$d

and thus keeps the target near the LJ axis in figure 2.

Normally the limits in 19 are set to zero when

Bd = 1 and opened up when Bd = 0 so that the lateral

look angle capability of the missile can be used in

this case.   Similarly for the control of the limits

of 16 by 15.   The limit 17 is not essential but may

be included to slightly extend the missile tracking

capability in cases when the field-of-view is needed.

In other words, when the magnitude part X of

the polar coordinates of the demanded look angle and/

or the actual separation between the target sight line

and missile axis, exceeds the respective limits imposed

by limiters 10 and 11, the signal Bd from gate 12 is

logical 1 whereby the limits imposed by limiter 19 are

each zero, i.e. the limiter does not pass on the signal

received thereby and the output demand signal LHd is

equal to the output signal provided by combiner 18.

Meanwhile the negative limit of LJd is reduced in

magnitude while the limit set by limiter 6 is at its

higher value $\emptyset$max.   In this state then, a certain

proportion of the control of the missile to achieve

apparent movement of the target to the demanded position

relative to the missile is achieved by rolling the

missile, the maximum roll rate set by $\emptyset$max being chosen

to give adequate stability.   When both λ and the

actual target/axis separation are less than the

respective limits, the proportion of the controlling

effect performed by roll control is curtailed while

the proportion performed by lateral steering about the
yaw and pitch axes of the missile, i.e. cartesian control,
is increased.   In this state, the Z axis demand signal
LHd equals L'Hd plus (Lhn-L'Hd) if (Lhn - L'Hd) is
between the limits LlH imposed by limiter 19 at this
time, i.e. Lhd equals LHn.   If the magnitude of
(Lhn - L'Hd) exceeds the LlH, then Lhd equals L'Hd',
plus the limit value.

     The signal Pd is fed to a roll rate autopilot
(not shown) of any suitable known construction and
operation.   Alternatively, provided that relatively
minor changes are introduced into the function by
which Pd is produced, for example at the limiter 6, a
roll position autopilot could be used.   The afore-
mentioned reference by Garnell and East illustrates
examples of autopilots and the theory of missile
control needed to adapt the illustrated arrangement
to any particular situation.   For example, a suitable
roll position autopilot is described in section 6.10
of the reference.

     Figure 2 is illustrated in function block form
since it could be implemented by a variety of electro-
mechanical or electronic devices of nature that will
be clear to those skilled in the art.   Advantageously,
however, the apparatus is implemented by one or more
computer processors, particularly microprocessor

devices, and any necessary associated electronics.
For this, the blocks in the figure should be regarded
as function representative blocks of an overall
algorithm rather than discrete items of hardware.
The signals LHd and LJd may be fed to two identical
autopilots one for pitch and one for yaw control-
suitable examples being shown in Garnell and East
section 6.3.   However, the roll capability of the
missile may be improved by advancing the demands in
the direction of rotation as a function of roll rate
to compensate for the lag produced by the actuator.
Fig. 3 shows a possible implementation. Those
skilled in the art will recognise that the priorities
of roll signals and conditioned steering signals may
be varied to advantage for other applications.